

The contamination of agricultural land in the metalliferous province of southwest England: implications to livestock

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(Accepted 12 October 1993)

Abstract

The widespread arsenic and associated metal contamination of soils, attributable to mineralisation and mining activity, in southwest England is reflected to only a limited extent in the composition of washed pasture herbage. However, owing to the limited translocation of both As and Fe to the above-ground portion of the plants, soil contamination can appreciably raise the concentrations of both elements associated with unwashed herbage. The consumption of soil contaminated grass by cattle therefore leads to soil ingestion being a major pathway of both elements to the livestock. Thus, up to 97% of the total dry matter intake of As may be via ingested soil. Reference to a control model indicates that cattle on mine contaminated land may ingest up to 31 times more As than livestock grazing uncontaminated pastures, but the implications of this enhanced intake are not known in detail.

1. Introduction

Metalliferous mining activity can lead to the contamination of the local environment as elements are released to the biosphere at a greater rate than would occur by the natural weathering of the underlying parent materials. Thus, in the UK, the most extensive areas of contaminated soils reflect (mainly historical) mining and associated mineral processing activities, complemented by the natural input from ore materials from geochemically distinct sources (Thornton, 1980). Historically, southwest England was the premier metalliferous mining centre of the world, and in Cornwall alone more than 600 underground mines have operated in the past extracting mainly Sn and Cu, along with As, W, Pb, Zn,

U, Fe, Sb, Ag, Mn and occasional amounts of Bi, Ni and Co (Dines, 1956). This production has left a legacy of dereliction and innumerable potential sources of contamination to the surrounding agricultural land. Soil and stream sediment sampling has indicated that some 1090 km² of land in southwest England, equivalent to 11.9% of the area surveyed, is contaminated by one or more of the elements, As, Cu, Pb and Zn (Abrahams and Thornton, 1987). Elevated concentrations of elements in forms available to plants are usually associated with these contaminated soils (Davies, 1971), and in the Tamar district the geochemically enriched nature of the soils is reflected in the arsenic and metal composition of barley seedlings and pasture herbage (Thoresby and Thornton, 1979). However, due to limited uptake and translocation, the trace-element concentrations of the above ground portion of the plant reflect to only a small degree the

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large amounts present in the soil. Soil ingestion and the direct soil–animal pathway of elements may therefore be important in such an area, as the barriers operative in the soil–plant–animal pathway of elements are by-passed. This paper reports the trace-element composition of soils in a mineralised and mined region of southwest England, and assesses the significance of geochemically enriched soils to livestock grazing contaminated pastures. In particular, the role of ingested soil as a source of both potentially toxic and beneficial trace-elements to the animal is investigated.

2. Site description and methods

Fieldwork was undertaken within the Hayle–Camborne–Redruth district of southwest England, an area important principally for the mining of Sn and Cu with associated As ores. Four soil traverses sampled across this study area have indicated the wide range of trace-element concentrations which are associated with this metaliferous province. Maximum concentrations of $727 \mu\text{g As g}^{-1}$, $564 \mu\text{g Cu g}^{-1}$, $685 \mu\text{g Zn g}^{-1}$ and $268 \mu\text{g Pb g}^{-1}$ were recorded from the sampled topsoils (0–15 cm) (Abrahams and Thornton, 1987).

Using both stream sediment maps and the soil traverse reconnaissance data, 12 farms which reflected the geochemical range of elements of interest were selected to evaluate the agricultural significance of the As and metal contamination. To observe the influence of the soil contamination on pasture herbage quality, a representative field was selected at each farm, within which three 3 m^2 plots were established at equal distances from each other and the field boundaries along the (imaginary) centre line of the long axis of the field. From the corners, mid-points and centre of each plot (i.e. nine points in all), samples of topsoil (0–15 cm) were collected with a hand screw auger and bulked, following which the entire pasture herbage was harvested with stainless steel shears at 2.5 cm above ground level (to avoid unnecessary soil contamination) providing the herbage was sufficiently developed.

Grasses were the primary plant species collected, though we made no attempt to fully evaluate the herbage species composition. Sampling of the herbage was undertaken during late April, late June and late August, to observe any seasonal fluctuations in composition.

In the laboratory, the herbage was split into two separate sub-samples; one sub-sample of each pair was then washed three times in de-ionised water before all the herbage samples were oven-dried at 80°C . Thus, the chemical differences (if any) between washed and unwashed herbage could be examined.

To evaluate the role of soil ingestion by cattle, 20 fresh faecal samples were randomly collected and bulked from the surface of each field during the three sampling periods of late April, late June and late August. Only the uppermost part of the dung pats were sampled, so as to avoid soil contamination. To compliment this work, during the spring period 20 bulked surface soils (depth of 0–15 cm) were collected from a 'W' traverse from each field investigated. The general geochemical characteristics of each field could then be determined from these samples.

We recognize that there are possible problems with some aspects of our sampling strategy. Previous work (Wigham, 1978) has demonstrated that in metal contaminated fields, local areas with very high element concentrations may be omitted when undertaking a 'W' traverse, and may not be represented in the bulk sample. Wigham (1978) also indicated that there may be considerable variability between small study plots in a single field subjected to enrichment through mineralization and mining contamination. In general, it was found that the degree of local variation between soil samples increases as the degree of soil enrichment increases. Thus, from a geochemical point of view, the 3 m^2 plots studied in our research may not be totally representative of the fields in which they are located.

Soil pH was determined on freshly sampled, air dried soil which had been passed through a 2 mm nylon mesh sieve. A 1:2.5 soil/water suspension was used for the determination by a pH electrode and meter (Avery and Bascombe, 1974). For As and metal analysis, less than 2 mm

soils were ground in an agate tema mill, prior to a nitric–perchloric acid digestion and subsequent analysis for Cu, Zn, Fe and Mn by atomic absorption spectrophotometry (Thompson and Wood, 1982). Arsenic was determined by inductively coupled plasma emission spectrometry following reduction to arsine by sodium tetrahydroborate. The oven-dried and milled herbage samples were analysed by similar methodologies and instrumentation. Lead could not be detected in many of the herbage samples (detection limit = $4 \mu\text{g g}^{-1}$), so data for this element are not presented in our discussion of the results. We do not regard this omission to be of major importance, however, as this metal is not a major contaminant of soils within the study area.

The Ti content of faeces was used as a stable marker of soil ingestion, as this element is usually present in relatively high concentrations in soils (several thousand $\mu\text{g g}^{-1}$) but in very small amounts (approximately $1 \mu\text{g g}^{-1}$ according to Healy (1968)), in uncontaminated pasture. Any Ti recorded in the faecal samples can thus be assumed to originate from a soil source. The Ti content of faeces and soils was determined spectrophotometrically, following a nitric–perchloric–hydrofluoric acid digestion. Soil ingestion rates were then calculated assuming a 70% digestibility of feed (Healy, 1968) and a dietary intake of $13.6 \text{ kg DM day}^{-1}$ using the equation

$$\% \text{ soil ingestion} = \frac{(1 - Dh) Ti_f \times 100}{Ti_s - Dh Ti_f}$$

where Dh is the digestibility of herbage, Ti_s is the Ti content of soil, and Ti_f is the Ti content of faeces.

3. Results and discussion

The soils from the study sites reflect a wide range of As and metal concentrations which vary from what may be called the uncontaminated (e.g. soil concentrations of $19 \mu\text{g As g}^{-1}$, $12 \mu\text{g Cu g}^{-1}$ and $29 \mu\text{g Zn g}^{-1}$ determined from the 'W' traverse samples) to the moderately and/or highly contaminated (e.g. $320 \mu\text{g As g}^{-1}$, $319 \mu\text{g Cu g}^{-1}$ and $365 \mu\text{g Zn g}^{-1}$) (Table 1). In our

study, the uncontaminated sites are mainly associated with podzolic soils developed over granite parent material, whilst the contaminated fields are associated with brown earths developed from underlying slates and basalts. Iron and Mn are not pollutants in the study area, but were analysed because of their important role in animal nutrition. Although these elements are not associated with the mineralisation and mining contamination, their concentrations in the soils are variable and reflect the nature of the underlying parent materials. Thus, relatively low concentrations of both elements are associated with the topsoils of the podzols (e.g. $120 \mu\text{g Mn g}^{-1}$ and 1.08% Fe), whilst higher amounts (maximum topsoil concentrations of $1650 \mu\text{g Mn g}^{-1}$ and 5.87% Fe) are recorded from the slate/basalt derived brown earths.

3.1. Trace-element composition of pasture herbage

The As and metal content of the soils is reflected to only a limited extent by the trace-element content of the washed pasture herbage collected from the 3 m^2 study plots. As an example, diagrams showing the relationship between soils and the herbage samples collected during the late April period are presented in Fig. 1 (a–e). Of the five elements studied, only the As and Cu content of the pasture herbage increases significantly with increasing soil concentrations ($P=0.001$ and 0.01 , respectively). However, the increase in pasture herbage content on the highly contaminated soils is relatively small compared with the large range ($17 - 388 \mu\text{g As g}^{-1}$ and $9 - 334 \mu\text{g Cu g}^{-1}$) of both elements recorded from the soil samples collected from the 36 plots studied. Iron and Zn concentrations recorded from the herbage are not significantly correlated with the soil content, whilst the Mn concentrations decrease significantly with increasing soil Mn content.

It is beyond the scope and objectives of our research to evaluate the mechanisms controlling the soil–plant relationships which are evident in our study, but our observations indicate that soil pH is probably an important factor controlling the

Table 1
The range of soil and washed herbage trace-element concentrations, rates of soil ingestion and calculated intake of the five elements studied

	Soil ingested (%)	Soil concentration ($\mu\text{g g}^{-1}$)		Washed herbage concentration ($\mu\text{g g}^{-1}$ DM)		Daily intake as soil (mg day^{-1})		Daily intake as herbage (mg day^{-1})		Total daily intake (mg day^{-1})		% Element ingested as soil	
		As	Cu	As	Cu	As	Cu	As	Cu	As	Cu	As	Cu
April	1.5–17.9	–	–	0.06–1.1	10–23	9–189	6–154	0.8–15	108–294	10–196	250–396	80–97	3.7–59
June	0.2–3.9	19–320	12–319	0.03–0.8	8–15	2–47	2–62	0.4–10	104–210	2.5–57	113–236	41–93	2.1–34
August	1.4–4.7	–	–	0.10–1.0	9–15	8–101	6–79	1.1–13	123–194	10–113	133–273	79–96	3.2–36
	Soil ingested (%)	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn
April	1.5–17.9	–	–	38–62	90–551	13–222	55–1448	494–692	1171–7311	590–914	1641–7563	2.1–28	2.1–45
June	0.2–3.9	29–365	120–1650	25–51	47–300	5–70	16–393	336–690	631–4057	370–700	710–4075	1.0–13	0.4–20
August	1.4–4.7	–	–	32–51	87–249	14–130	57–600	424–661	1145–3299	444–750	1346–3363	2.6–21	1.9–29
	Soil ingested (%)	Fe		Fe		Fe		Fe		Fe		Fe	
April	1.5–17.9	–		101–1224		4920–49232		1314–16240		12986–55022		30–95	
June	0.2–3.9	10800–58700		42–275		1224–14971		564–3690		2383–17125		45–93	
August	1.4–4.7	–		94–560		5155–26384		1238–7261		7764–29482		64–92	

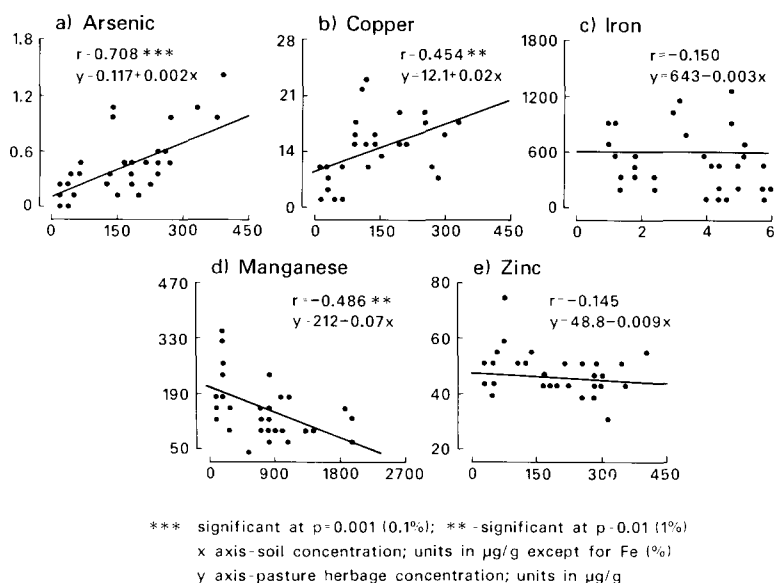


Fig. 1. Arsenic and metal concentrations recorded from the washed herbage samples collected during late April.

uptake of Mn by the pasture species (the correlation coefficient determined from these two variables for the late April period = -0.567 ; $P = 0.05$). The podzolic soils 'low' in Mn are moderately and slightly acidic ($\bar{X} = 5.5$ pH units, $n = 12$) in reaction, whilst the 'high' Mn soils developed from the slate/basalt parent materials have a typically slightly acid to alkaline pH status ($\bar{X} = 6.2$ pH units, $n = 24$). The availability of Mn to plants is known to be reduced when the soil pH is greater than 6.0 (Batey, 1971).

The relationships between the trace-element content of soils and herbage are similar in June and August to those observed during April, although the concentrations determined from the washed herbage does differ according to season. Thus, the trace-element concentrations of the washed herbage sampled during late June are generally lower than those recorded from the spring and late summer samples (Fig. 2).

3.2. The relative accumulation of the five elements by pasture herbage

The relative accumulation of the five elements studied can be calculated by dividing the washed herbage content of each element by the soil con-

centrations (Timperley et al., 1970). As an example, the relative accumulation ratio's calculated for the late April period are outlined as graphs in Fig. 3. The accumulation of elements by plants is dependent upon a number of factors (such as, for example, the species of plant, or the soil pH which has an important influence on the availability of elements), but the relative accumulation ratio's reveal two major points of interest relevant to our discussion. First, from the samples collected and analyzed in this study, the uptake and/or translocation of As and, to a lesser extent Fe, by the pasture herbage is restricted compared with the other three elements investigated. Thus, most of the relative accumulation ratios for As are less than 0.01, whilst minimum ratios of 0.033 for Cu, 0.037 for Mn and 0.07 for Zn were calculated from the data collated in this study. Second, however, the relative accumulation of all the five elements is not constant, but varies according to the soil concentrations of the study plots. Low ratio values are associated with those plots with the highest soil concentrations.

For the elements Cu, Mn and Zn, graphs showing the relative accumulation of each element plotted against the soil concentrations give an approximation to a hyperbolic curve (Fig. 3

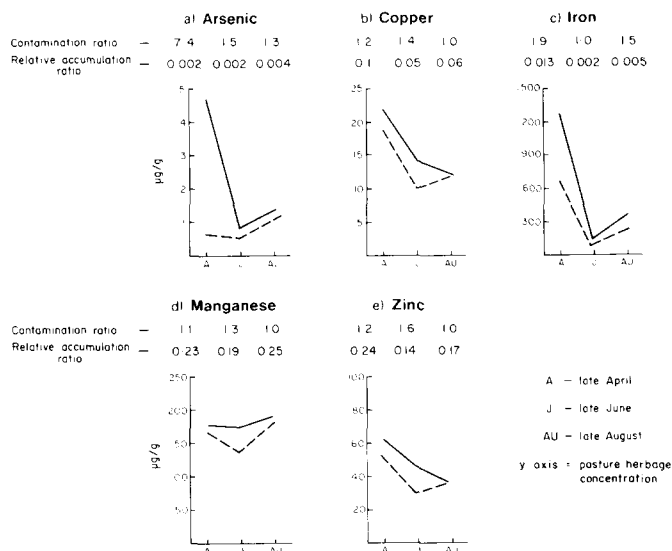


Fig. 2. Seasonal variation of As and metal content in washed (dashed line) and unwashed (continuous line) herbage collected at one of the study sites. The contamination and relative accumulation ratio's determined for each element during each period of sampling are noted above the graphs.

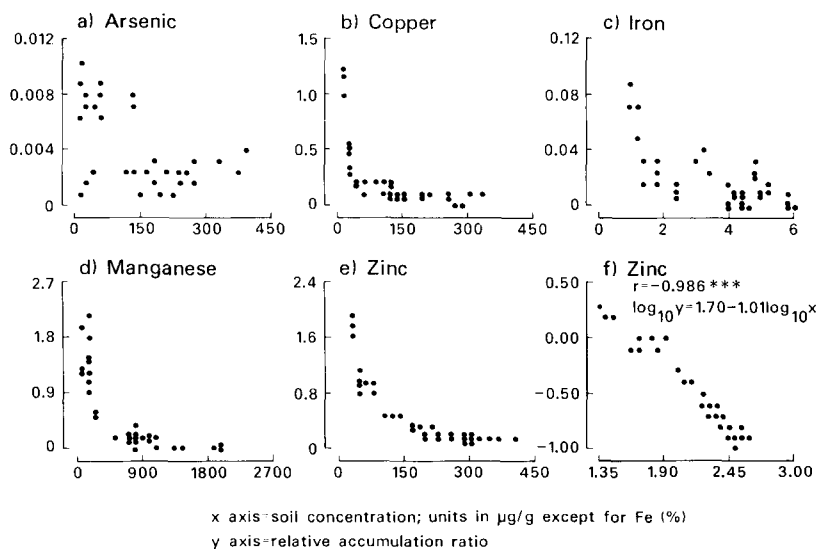


Fig. 3. Relative accumulation of each element determined from samples collected during the late April period. *** = significant at $P=0.001$ (0.1%).

(b), (d) and (e)). For As and Fe, a similar relationship is also apparent, despite a greater scatter of the plotted observations on the graphs (Fig. 3 (a) and (c)). Logarithmic transformation of the X (soil concentration) and Y (relative accu-

mulation ratio) variables will produce a linear inverse relationship for all of the five elements. Pearson correlation r and r^2 coefficients demonstrate that the Cu, Fe, Mn and Zn concentrations of the pasture herbage can be predicted very ac-

curately from these logarithmic plots (e.g. Fig. 3 (f)). The coefficient of determination (r^2) values for As, however, are low (range 12.4–19.6%) and the correlation (r) coefficients are not highly significant compared with the other four elements. Thus, the As concentrations in the herbage can be predicted with slightly greater accuracy from the linear regression equations derived from the observed soil/plant relationships (e.g. Fig. 1 (a)). The importance of these observations will become apparent later in our discussion.

3.3. The contamination of pasture herbage by soil

Soil contamination of herbage can arise from soil splash or ruminant poaching and can mask the true trace-element content of the plant. To investigate this further, unwashed herbage samples were collected from the study plots, and following analysis a simple unwashed herbage/washed herbage ratio, referred to here as the contamination ratio, was used to assess the degree of soil contamination.

In this study, both As and Fe are good indicators of soil contaminated herbage. For both elements, the contamination ratio's are generally higher than those calculated for Cu, Mn or Zn. Fig. 2, for example, illustrates the As and Fe contamination of herbage caused by the adherence of soil particles onto the plant surface during the late April period. Our studies have shown that the As concentrations of the unwashed herbage can be up to 63 times greater (and for Fe up to ten times greater) than those amounts recorded from the same samples which were washed with de-ionised water. The reason why herbage is particularly vulnerable to As and Fe contamination by soil can be attributed to the low relative accumulation of these elements by the plants. As the herbage contains low As and Fe concentrations relative to the high amounts found in the soil, any soil particles which adhere to the plant surface will significantly enhance the apparent As and Fe content of the plant.

The concentrations of As and metals associated with the unwashed herbage vary according

to the season of sampling (Fig. 2). Generally, lower concentrations of all the five elements studied were associated with the samples collected during late June. During this sampling period, the growth of grass was well established and the susceptibility of the grass to soil contamination was low. The highest concentrations recorded from the unwashed samples were associated with the late April period. It was noted at the time of sampling that the pasture during this period was short and thus likely to be vulnerable to soil contamination. At one of the plots studied during this sampling period, values of $58 \mu\text{g As g}^{-1}$, $74 \mu\text{g Cu g}^{-1}$, $1\ 1750 \mu\text{g Fe g}^{-1}$, $300 \mu\text{g Mn g}^{-1}$ and $103 \mu\text{g Zn g}^{-1}$ were recorded from the unwashed herbage. These data compare with values of $1.05 \mu\text{g As g}^{-1}$, $17 \mu\text{g Cu g}^{-1}$, $1360 \mu\text{g Fe g}^{-1}$, $138 \mu\text{g Mn g}^{-1}$ and $49 \mu\text{g Zn g}^{-1}$ determined from the washed herbage collected from the same site. The disparity in these values shows the importance and necessity of an efficient washing technique which is required when undertaking trace-element studies on plant samples. Previous work has reached similar conclusions, and demonstrated the difficulty of efficiently washing plant material (e.g. Fortmann and Johnson, 1984).

3.4. The total daily intake of As and metals by cattle grazing within the study area

The total daily intake by cattle of the five elements investigated can be calculated by assuming a dietary intake of $13.6 \text{ kg DM day}^{-1}$, and by calculating the proportion of soil and herbage which constitutes the diet; a knowledge of the relevant soil and washed herbage concentrations is also obviously required for undertaking the calculations. Table 1 provides a summary of the data derived from the 12 farm sites studied, whilst Fig. 4 (a–e) incorporate all of the total daily intake values recorded for each element during the three periods of sampling. These diagrams indicate that the total daily intake for As and Cu is positively correlated with the soil concentrations, but no significant trend is observed for the elements Fe, Mn and Zn. The r^2 values range from 3.7% for Mn to 34% for As, and in-

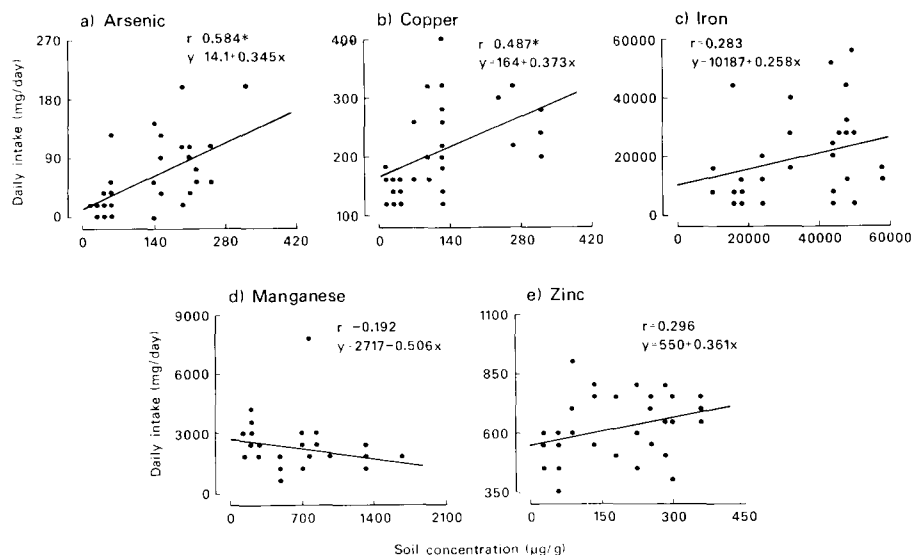


Fig. 4. The calculated daily intake of As and metals at each of the study sites investigated. * = significant at $P=0.05$ (5%).

indicate that much of the variation observed for the daily intake rates are not fully accounted for by simple variations in the soil concentrations. This can be attributed to the following two factors:

(1) The trace-element concentrations of the pasture herbage. Figs. 1 and 2 demonstrate the trace-element variability of the pasture herbage. The herbage concentrations vary both between plots and, on a seasonal basis, within plots.

(2) Soil ingestion. The analysis of faecal Ti indicates that soil is a constituent of the ruminant diet accounting for, on average, 5.6%, 1.45% and 3.0% of the total dry matter intake in late April, June and August, respectively (Table 2). On nearly all of the 12 farms studied, the rate of soil ingestion varied with the season of sampling. Soil ingestion is particularly elevated in late April (maximum recorded value = 17.9% of the total dry matter intake) and thus reflects the time of soil contaminated herbage. Soil ingestion falls rapidly in early summer with the flush of new pasture growth and the decreasing vulnerability of the herbage to soil contamination, but increases again in the late summer when grass is less abundant. This seasonal trend in the rate of soil ingestion corresponds to the general sea-

Table 2

Seasonal variation of soil ingested by cattle at the 12 farms investigated

Sample period	Percentage of soil as total dry matter intake	
	Mean (\bar{X})	Range
Late April	5.64	1.47–17.9
Late June	1.49	0.18–3.91
Late August	3.01	1.36–4.66

$n = 12$ for each sampling period.

sonal concentrations of the five elements in the pasture herbage. As a result, the total daily intake of the five elements follows a similar trend, with the lowest intake rates being associated with the late June period.

As the relative accumulation by herbage of Fe and especially As is low, ingested soil can be a particularly important source of these two elements to grazing cattle. The percentage of As ingested as soil varies from 41% to 97% ($\bar{X} = 85\%$), whilst for Fe the percentage ingested as soil varies from 30% to 95% ($\bar{X} = 76\%$). In comparison, the percentage range for Cu is 2.1 – 59% ($\bar{X} = 20\%$), for Mn the range is 0.4 – 45%

(\bar{X} = 13%), and for Zn the range is 1 – 28% (\bar{X} = 11%) (Table 1).

The total daily intake of the five elements studied is significantly increased as a result of soil ingestion by the ruminant. One site located in an area associated with relatively low soil trace-element content provides a particularly good example where the high soil ingestion rate during late April (17.9%) appreciably raises the total daily intake of As (126 mg day⁻¹), Fe (44 102 mg day⁻¹) and, to a lesser extent, Cu (262 mg day⁻¹), Zn (914 mg day⁻¹) and Mn (4447 mg day⁻¹). These figures can be compared with the median values (19.7 mg As day⁻¹, 18 165 mg Fe day⁻¹, 160 mg Cu day⁻¹, 606 mg Zn day⁻¹ and 2594 mg Mn day⁻¹) obtained for the same month at those other sites which have a similar soil geochemical status but where the rates of soil ingestion was lower. Conversely, periods of low soil ingestion are associated with a low total daily intake. For example, the low rate of soil ingestion (0.18%) at one contaminated site during late June resulted in a daily intake of 11.6 mg As day⁻¹, compared with the median of 46 mg As day⁻¹ recorded from the remaining sites of similar soil geochemical composition where soil ingestion was higher.

3.5. The theoretical intake of trace-elements by cattle grazing uncontaminated soils

The relevance of the dietary intake values outlined in Table 1 is difficult to determine owing to the lack of information in the literature. Whilst toxicological reviews, information relating to the trace-element content of animal foodstuffs, and trace-element requirement threshold values are available (e.g. Underwood, 1977; ARC, 1980; Clarke et al., 1981; Bartic and Piskac, 1981), much of the information is difficult to apply to the practical situation which exists in southwest England. Recent work (ICRCL, 1990) however has proposed soil “threshold trigger concentrations”, defined as those concentrations below which mine contaminated soil is considered to be safe. The proposed threshold concentrations of 50 µg As g⁻¹ and 250 µg Cu g⁻¹ are exceeded at some of the sites investigated in our study, al-

though the implications of this to grazing livestock is still uncertain. In order to further assess the significance of the widespread soil contamination which persists in southwest England, we have calculated a theoretical control model which indicates the potential trace-element intake by cattle grazing uncontaminated pastures. These calculations are presented in Table 3, and are based on the following assumptions:

(1) That the rates and factors influencing soil ingestion are similar to those observed at the sites investigated in southwest England. The rates of soil ingestion shown in Table 3 are the average (mean) rates of soil ingestion observed in our study of the 12 sites (Table 2).

(2) The theoretical model requires typical uncontaminated soil concentrations which are required for the calculation of daily intake rates. Such data are available from a number of sources; our information has been extracted from the work of Berrow and Burridge (1980).

(3) The theoretical model requires the washed herbage concentrations which can be expected to be associated with the uncontaminated soils outlined in section (2) above. For the elements Cu, Fe, Mn and Zn, these herbage concentrations were derived from the regression equations calculated following logarithmic transformation of the relative accumulation data (e.g. Fig. 3 (f)). For As, the linear regression equations derived from the herbage and soil concentrations (e.g. Fig. 1 (a)) were used for the prediction.

By making the above assumptions, the calculated theoretical daily intake values presented in Table 3 can be taken to represent a control situation against which the daily intake values found in southwest England can be compared. For As, Table 3 indicates that under uncontaminated conditions a total daily intake of only 6.3 mg day⁻¹ may be consumed by cattle during the spring period. In contrast, up to 196 mg As day⁻¹ was actually consumed by cattle grazing the pastures in southwest England at the same time of the year (mean = 96 mg day⁻¹); this is 31 times the value calculated in Table 3. The main reason for this difference can be attributed to ingested soil. Our field studies show that in April, the maximum daily intake of As via herbage was re-

Table 3

The theoretical daily intake of As, Cu, Fe, Mn and Zn by cattle grazing pastures established on soils with typical (uncontaminated) soil trace-element concentrations

	Soil ingested (%) ¹	Soil conc. ($\mu\text{g g}^{-1}$) ²		Washed herbage conc. ($\mu\text{g g}^{-1}$ DM)		Daily intake as soil (mg day^{-1})		Daily intake as herbage (mg day^{-1})		Total daily intake (mg day^{-1})		% Element ingested as soil	
		As	Cu	As	Cu	As	Cu	As	Cu	As	Cu	As	Cu
April	5.64	–	–	0.13	11	4.6	15	1.7	141	6.3	156	73	9.6
June	1.49	6	20	0.08	8	1.2	4.1	1.1	107	2.3	111	52	3.7
August	3.01	–	–	0.20	11	2.5	8.2	2.6	145	5.1	153	49	5.4
	Soil ingested (%)	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn	Zn	Mn
April	5.64	–	–	48	128	38	614	616	1643	654	2257	5.8	27
June	1.49	50	800	34	106	10	162	456	1420	466	1582	2.1	10
August	3.01	–	–	38	137	20	327	501	1807	521	2134	3.8	15
	Soil ingested (%)	Fe		Fe		Fe		Fe		Fe		Fe	
April	5.64	–	–	368	–	30682	–	4723	–	35405	–	87	–
June	1.49	40000	–	102	–	8106	–	1367	–	9473	–	86	–
August	3.01	–	–	216	–	16374	–	2849	–	19223	–	85	–

¹Based on the mean rates of soil ingestion observed in southwest England.

²From Berrow and Burridge (1980).

corded as 15 mg day^{-1} , whereas the intake from soil varied from 9 to 189 mg day^{-1} (mean = 91 mg day^{-1}). Table 1 indicates that between 80 and 97% of the As consumed by grazing cattle in southwest England was via soil intake, although as Table 3 demonstrates, even under uncontaminated soil conditions ingested soil may still be the major pathway of As to the animal.

Soil ingestion is also important in supplying Fe to cattle. Table 3 indicates that soil provides over 80% of the total dry matter intake of this element to animals grazing uncontaminated pastures. The figures calculated for Fe in Table 3 are of the same order of magnitude as those observed under field conditions in the southwest England study. As Fe is not a major contaminant in our study area, the soil concentrations used in the calculations for both Tables 1 and 3 are on the whole similar. This applies also to Mn. Table 3 indicates that cattle grazing pastures established on uncontaminated

soils will ingest typically between 10 and 27% of their total Mn intake as soil, depending on the time of year. In southwest England, mean values of 20% (April), 7.3% (June) and 12% (August) were observed.

The total daily intake of Cu and Zn outlined by the control model approximate to those sites in southwest England which are not elevated in their Cu and Zn soil concentrations. The ingestion of soil at these sites supplies only a small percentage of Cu and Zn to the grazing animal. In southwest England, the source of soil in supplying Cu and Zn only becomes more substantial at the contaminated sites. This may result in an elevated total daily intake of both elements. Thus, the maximum total daily intake rates of Cu (396 mg day^{-1}) and Zn (914 mg day^{-1}) compare with values of $156 \text{ mg Cu day}^{-1}$ and $654 \text{ mg Zn day}^{-1}$ from the control model.

3.6. Implications of contaminated soils and soil ingestion to the health of cattle

There is currently no evidence to suggest that the widespread trace-element contamination of soils is seriously affecting agricultural productivity. Clinical toxicity symptoms in grass species are restricted to derelict mine sites of little importance to agriculture. Thomas (1980) reports that the contamination of soils by As does not manifest itself in the large scale poisoning of farm animals. The significant correlation between the daily intake rates of As and the concentrations of this element in the faeces of cattle (Fig. 5) supports the view that a certain proportion of the trace-element is not biologically absorbed to any great extent. This may be due to the fact that soil is the major source of the element to the grazing cattle. According to Hegan and Eagle (1944; cited by Clarke et al., 1981), the rate of As excretion varies with the type of compound and is generally inversely related to the toxicology. It is probable that under the freely drained soil conditions which are widespread throughout the part of southwest England studied, arsenate is the predominant inorganic species of the element (Peterson et al., 1981). This species is less toxic than the arsenite form, and apparently does not accumulate in vertebrates (Schroeder and Balassa, 1966). However, any possible effect of As and associated elements ingested by cattle in south-

west England remain to be determined. A certain amount of As is absorbed; this is known as it has been noted that animals moved from a farm with little As contamination to one which is heavily contaminated (or vice-versa) lose condition to a greater extent than normally expected as a result of a change of field or environment (Thomas, 1980). This change in condition can manifest itself clinically in the appearance of the animals coat (Thornton, 1978). Some of the absorbed As may be excreted in the milk of suckler cows (Clarke et al., 1981), and Thomas (1980) records that the milk may be contaminated with unacceptable concentrations of this element which can be potentially dangerous to calves as they are particularly susceptible to trace-element excess. No known research, however, has been undertaken on this potential problem. Indeed, although the occurrence of soil ingestion has been known for a considerable amount of time (e.g. Field and Purves, 1964), the number of studies to date investigating the importance of this phenomenon has been remarkably limited. Clearly, there is a need to further study the possible impact of these ingested soils which are enriched in As and other elements. It is possible, for example, that in addition to supplying potentially toxic elements such as As to the animal, other elements of nutritional importance such as Co may be supplied via the ingested soil. Iron is also of interest here, as it may prove to be an antagonist to As absorption thereby reducing the impact of the enhanced As intake. In this context, it is interesting to note that moist and freshly prepared ferric hydroxide remains the classical antidote for As poisoning in animals (Clarke et al., 1981).

4. Conclusions

Although the soils throughout a considerable area of southwest England are enriched in certain elements, our studies indicate that this enrichment is reflected to only a limited extent by the composition of washed pasture herbage. Although the As and Cu content of the pasture herbage increases significantly with increasing soil concentrations, the increase is relatively small

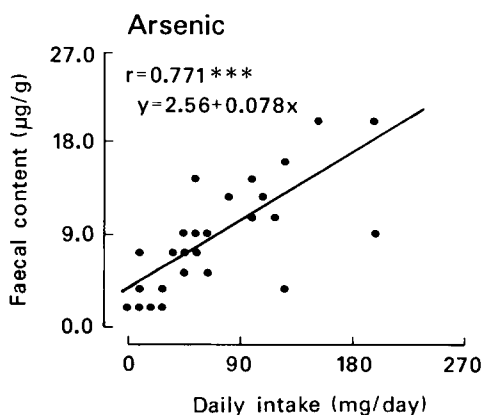


Fig. 5. The faecal content of As related to total daily intake. *** = significant at $P=0.001$ (0.1%).

when compared with the large range of both elements recorded from the soils of the 36 study plots which were sampled. The composition of the pasture herbage varies seasonally, with the concentrations of As, Cu, Zn, Fe and Mn being lower during the mid-summer period.

Owing to the restricted uptake and/or translocation of both As and Fe to the above ground part of the plant, pasture herbage is vulnerable to soil contamination of these elements, and considerable differences in the As and Fe concentrations of washed and unwashed herbage can occur. The degree of soil contamination appears to be related to the supply of grass available to the animal, although such an observation is yet to be quantified. Our studies demonstrate the importance of the direct soil–animal pathway of elements. This is especially apparent for As, with up to 97% of this element reaching the animal via ingested soil. Reference to a control model indicates that the cattle of southwest England may ingest up to 31 times more As than livestock grazing uncontaminated pastures. The implications of this elevated exposure of As to cattle which is attributable to soil ingestion needs further investigation.

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